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A Role-Functional Model of Design Problem Solving

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13. ABSTRACT *(Maximum 200 words)*
Eight individuals learned about a fictitious vehicle, then designed instruction about it. The individuals were relative novices in instructional design, both in their small amount of professional training in the activity and the novelty of the subject matter. Protocols were coded for subproblems, types of knowing, and problem-solving operators. A hypothesis is presented about the organization of problem-solving activity in this design task, in the form of a model in which functional roles are assigned to metaphorical agents in a design committee.

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This report discusses processes of solving an ill-structured problem. We asked individuals to design instruction in a domain in which they were relatively unfamiliar. The goal of this activity was relatively open-ended, and a solution of the problem required significant construction of what the various components of the problem were, as well as construction of solutions.

Our study contributes to a growing body of analyses in cognitive science of relatively ill-structured problems, especially in design tasks. Reitman (1965) discussed a protocol recorded as a musical composer worked on a fugue. Simon (1973) discussed a social process of deciding on features of a sailing ship. Getzels and Csikszentmihalyi (1976) studied art students composing drawings. Several investigators have studied composition of written essays (e.g., Bereiter & Scardamalia, 1987; Hayes & Flower, 1980). Design of experiments in microbiology was modeled by Stefik (1981). Jeffries, Turner, Polson and Atwood (1981) studied design of software. A problem of designing an administrative-political policy was studied by Voss and his associates (Voss, Greene, & Penner, 1983). Kant and her associates (Kant, 1985; Kant & Newell, 1983) studied and modeled design of an algorithm. Design of a residential building was studied by Akin (1984). Allen (1988) studied graphics designers working on posters. Ullman, Dietterich, and Stauffer (1988) studied design problem solving in mechanical engineering. Pirolli and Berger (1991) studied instructional designing by experienced professionals, and Goel and Pirolli (1991) presented a general discussion of design problem solving using the idea of a design problem space.

Two general features characterize problem solving in these various design contexts. First, design problem spaces are *functionally diverse*, involving a variety of goals and constraints that have to be met simultaneously. Second, design problem-solving activity is *constructive*, in that subgoals and materials for solving the problem have to be generated by the problem solver, rather than being given as part of the problem.

Functional diversity and constructive activity are matters of degree. We take the view here that design problem solving can be analyzed by extending concepts of information processing that have been used successfully in analyzing well-defined problems (Newell & Simon, 1972). Indeed, solution of well-defined problems such as geometry proof exercises can include constructive processes and interaction of multiple problem spaces (Greeno, Magone & Chaiklin, 1979). Our discussion here contributes a discussion of design problem solving that is grounded in information-processing concepts and thus emphasizes theoretical continuity of design problems with other, more well-defined, tasks.

Instructional Design

A task in instructional design typically involves specification of a topic and an audience for whom the instruction is intended. The designer then constructs a plan (at some level of detail) that specifies a sequence of events, sometimes called instructional transactions, involving various subtopics and various instructional activities. (Instructional activities often are presentations of information by a teacher, but also can include discussions or other activities by students.)

Activities of instructional design are influenced by two kinds of domain-specific knowledge. One is detailed knowledge and experience of teaching in the subject-matter domain of the instruction; the other is knowledge and experience of procedures of designing instructional materials.

Experts in an instructional domain include professional workers in the domain (e.g., mathematicians for instruction in mathematics, writers for instruction in literature, or auto mechanics for instruction in car repair) and people who have significant experience in teaching in

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the domain. The instructional designs constructed by subject-matter experts reflect their rich understanding of the organization of concepts and principles of the domain. The instructional designs constructed by expert teachers (often as lesson plans) reflect their rich experience of teaching the material and finding ways to present information and engage students that do or do not result in students' learning.

The large literature on instructional design is mainly prescriptive, consisting of heuristic principles that can be used to organize the design process (e.g., Reigeluth, 1983). These principles correspond to a complex set of domain-specific methods and strategies in the practices of many experienced instructional designers (Pirolli & Berger, 1991).

Our research, on the other hand, examined design problem-solving activity of relative novices. Our designers were familiar with the activities of teaching, but were asked to design instruction with material that they had just learned. They had supervised practice in constructing lesson plans, but did not have specific courses or work experience in instructional design.

Empirical Study[1]

METHODS

Participants. Participants were eight students in the Stanford Teacher Education Program (STEP). Four of the participants had recently graduated from the program, and four were new students at the beginning of the one-year program. Within each group of four participants, one male and one female student were planning to teach high school science, and the other male and female students were planning to teach either high school mathematics or social studies. Participants were recruited through an announcement in one of their classes and were paid for their participation.

Subject-Matter. The experiments used a fictional device as the topic for instruction. The device, a fictional vehicle called the VST 2000, was developed in previous research by Greeno and Berger (1987; 1990). The VST 2000 has alternative sources of energy, which are displayed on a computer screen along with displays of switches that can manipulated using a mouse. By changing switch settings, connections between different components and states of the components are changed, resulting in simulated operation of the vehicle with its different sources of energy. The display that the participants interacted with is shown in Figure 1. (The components of the fictional device are analogous to components of a stereo system: the solar pack is like a radio receiver, the tablograph is like a turntable, and the vegetor is like a cassette player-recorder. This analogy was not mentioned to our participants, and none of them indicated that they recognized the analogy.)

The domain of this fictitious device is advantageous for three reasons: (1) it is of manageable size and complexity so that a detailed representation of knowledge about the device can be specified; (2) participants' knowledge about the device can be controlled to a great extent because it is not a subject matter that our participants have studied previously; and (3) a computer-based display and simulation were available for use in the research.

Procedure. Each participant took part in two one- to two-hour sessions on separate days. On the first day, participants learned about operating the VST2000 using a computer-based tutorial. On the second day, they were asked to think aloud as they designed two pieces of instruction about the vehicle.

[1] A more complete description of this study is in Greeno, Korpi, Jackson, & Michalchik (1990).

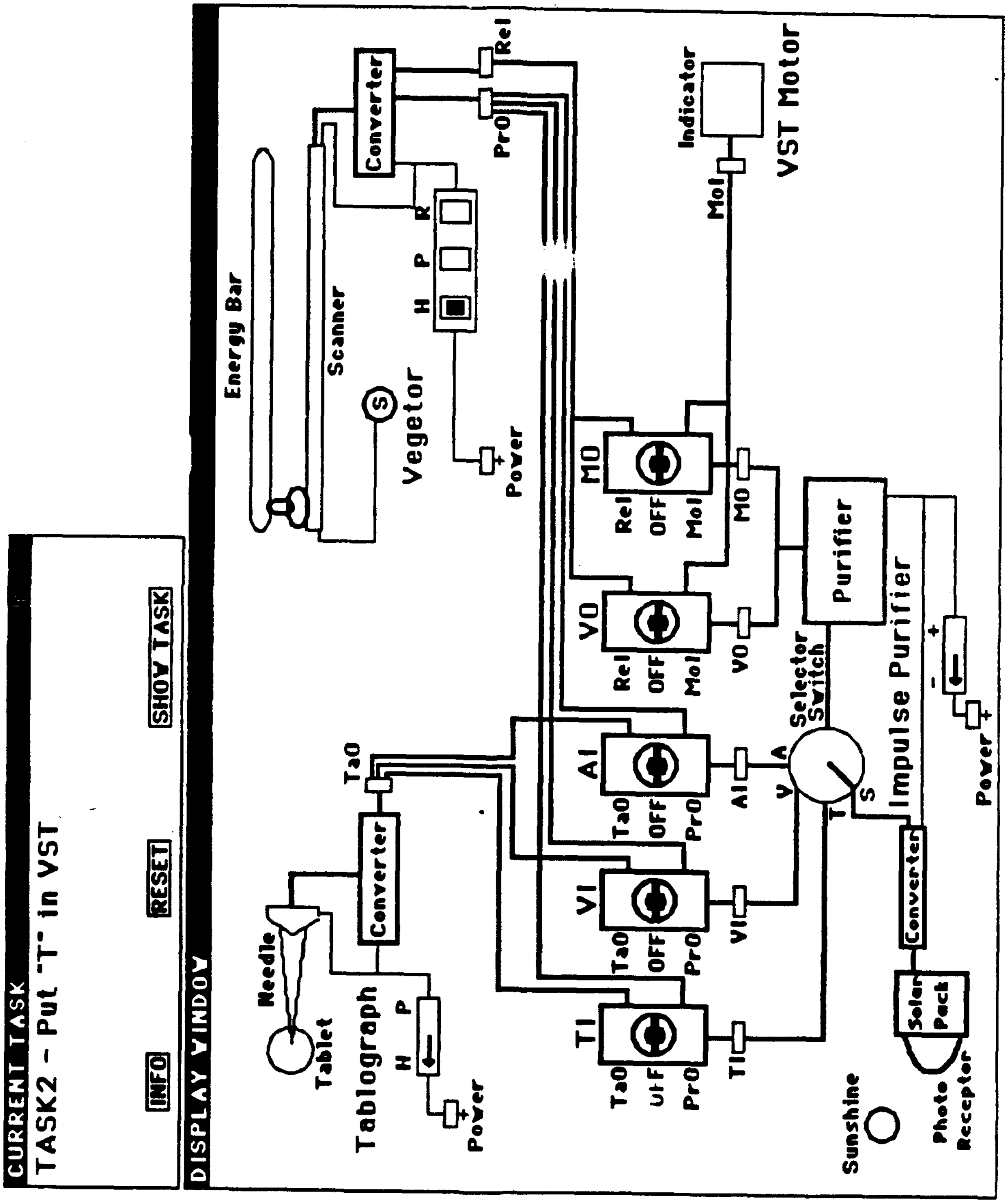

Figure 1. Display seen by participants.

On the first day, participants went through a computer-based tutorial for the VST2000. In the tutorial, participants read text interspersed with 13 multiple-choice questions about the VST2000, its components, and the functional relations among the components. Some of the questions required the participant to manipulate the switches on the VST2000 to simulate the operation of the device. The computer-based tutorial program repeated instructional text when a participant gave an incorrect answer. Participants were instructed to think aloud as they answered the questions, and their verbalizations were recorded on audio tape. An interviewer operated the tape recorder, reminded participants to think aloud while answering the questions, and conducted a brief interview at the end about the participant's college major and background in science and technology.

On the second day, the participants were given training in verbalizing their thoughts. Following a procedure adapted by Korpi (1988) from Ericsson and Simon (1984), participants were instructed to think aloud while solving a series of problems. When the participant said that he or she was comfortable with the thinking-aloud procedure he or she was asked to design instruction for one of the two goals described below. After completing the first design, the participant was asked to design instruction for the second goal. The order in which the tasks were presented was balanced across the participants.

For one piece of instruction, called *operations*, participants were asked to design materials that a teacher could use to instruct high-school-aged students in the operation of the VST2000. The participants were told to assume that the VST2000 was a real machine and that they should design a general plan to use in teaching its operation.

For the other piece of instruction, called *principles*, participants were asked to design materials that a teacher could use with high-school-aged students in a general science course. The VST2000 was to be used to illustrate general principles about science and machines. The participants were given a card that described some general principles that they might address in their design. These were: storing energy, extracting stored energy, converting energy, transporting energy, and purifying energy.

During work on the design, the participant was permitted to refer to the VST2000 screen display, to write notes, and to ask the experimenter questions. After finishing each piece of instruction, the participant was asked to review the design in relation to six aspects of instruction: main topics, sequencing, methods of presentation, materials, activities, and questions or problems for students to work on.

After finishing both tasks, the participant was asked about his or her past experiences with teaching and instructional design to comment on the tutorial.

RESULTS

Transcriptions of the audio-taped records of each participant's design activity were coded regarding three aspects of problem solving: subproblems, types of knowing, and operators.

Subproblems. Subproblems are activities that contribute to satisfying requirements of a design. An instructional design includes specifications of content to be included, types of instructional transactions that should occur, a sequence in which the material and transactions will occur, and other properties. Designers also specified or clarified requirements of the design task, clarified aspects of the subject matter, and engaged in planning and monitoring of their progress.

Figure 2 shows the distribution of activity for the 10 subproblems that were coded. The abbreviations along the abscissa stand for the following subproblem labels: (1) determine content, (2) determine sequence, (3) determine timing (durations), (4) determine instructional transactions, (5) determine instructional resources, (6) determine constraints or requirements of the design task, (7) introduce own constraints, (8) monitor progress on the design or set out a plan for the design process, (9) clarify the subject matter to be taught, and (10) non-design activities related to the instruction. The quantitative measure was based on the transcripts; we measured the lengths of segments that were coded in each subproblem. The unit of length, 1 cm, corresponded to about six characters, or slightly more than one word. Many segments of the transcripts were coded as contributing to more than one of the subproblems.

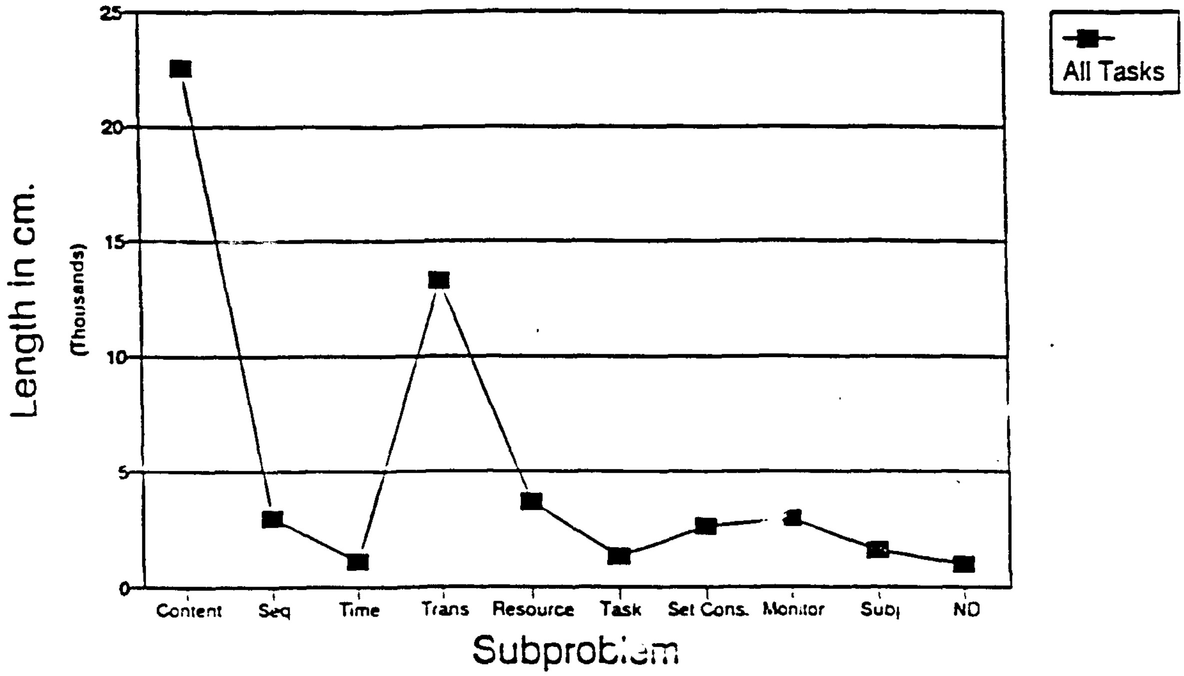

Figure 2. Lengths of transcriptions for subproblems.

Note that by far the greatest amount of activity involved specifying what would be taught -- the content -- and how it would be taught -- the transactions. The sequence of the instruction was determined incidentally. The sequence of events was considered many times -- this subproblem had the highest frequency of occurrence -- but almost always in very brief references.

The general pattern of Figure 2 was quite consistent across all the subsets of our data. (Graphs of these comparisons are included in Greeno et al., 1990.) Comparing the Principles and Operations goals, there was some more work on determining content in the Principles designs than in the Operations designs, but Determine Content had the greatest amount of activity in both sets of transcripts. There was also about twice as much activity of Monitoring in the Principles designs as there was in the Operations designs. Comparing the STEP graduates with beginning students, the main difference was that the graduates' protocols were somewhat longer, but the profiles of the two groups were very similar. Comparing the designs that participants did first and second in the sequence, the second designs were somewhat longer, especially in the activity for determining the content and transactions. Participants were more active in introducing constraints and clarifying subject-matter issues in their second designs, and attended less to considering instructional resources, than they were in their first designs.

We constructed graphs of the subproblem activity longitudinally across the transcripts for the eight designers on each of their two designs. (These graphs are included in Greeno et al., 1990.) Two patterns occurred quite frequently. In the most frequent pattern (six of the 16 designs, with three others that were quite similar), the designer spent one or two short episodes at the beginning clarifying the task. The main part of each design has a major emphasis on Determine Content, with brief bits of Determine Sequence within each episode. The designers occasionally specified instructional transactions or, less often, instructional resources, while proposing the content. Monitoring occurred quite regularly throughout the design work.

A second pattern that occurred frequently (five of the 16 designs) showed about an equal balance of activity on the Determine Content and Determine Transactions subproblems throughout work on the design. Instructional transactions and content usually were specified in separate episodes, while in the first pattern these were transactions and content were usually discussed together.

Types of knowing. We coded different types of knowing according to inferences that we made about different kinds of information that designers drew on in their design activities. These would correspond to different constituents of a knowledge base for design problem solving. We identified three general groupings: subject-matter content knowing, pedagogical knowing, and pedagogical content knowing.

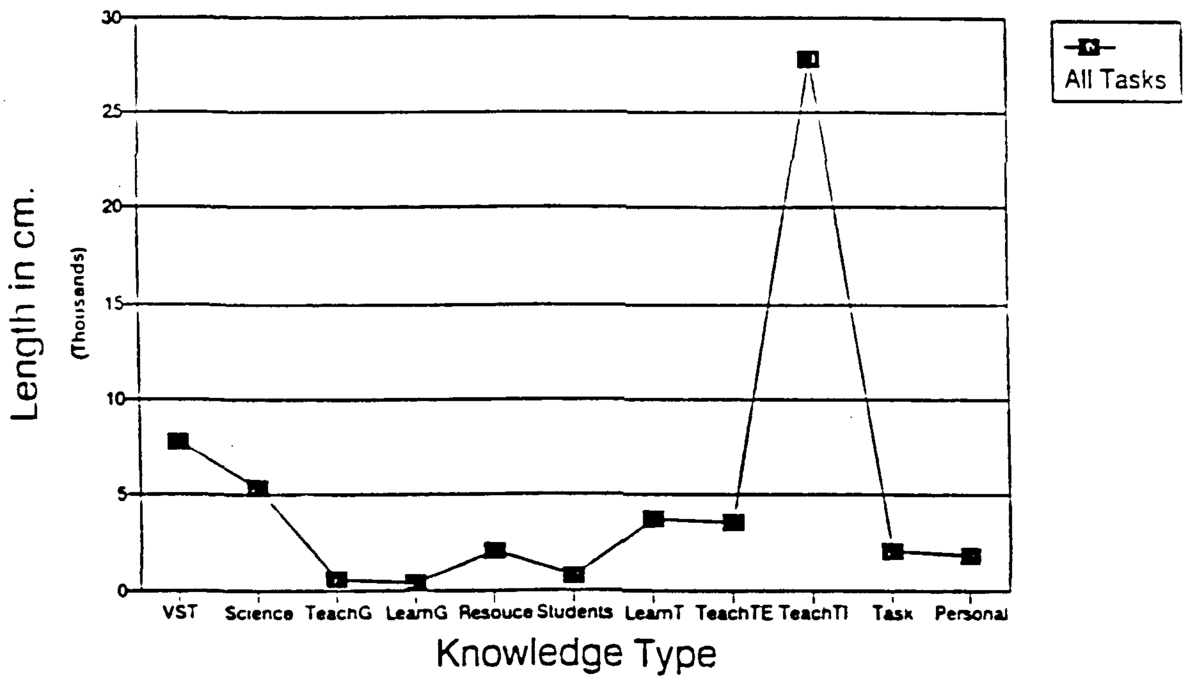

Figure 3. Lengths of transcriptions for types of knowing.

Figure 3 shows the distribution of activity across all the designs and designers of 11 types of knowing that we coded. The abbreviations across the abscissa stand for: (1) information about the VST2000, (2) general information about science, (3) general information about teaching, (4) general information about learning, (5) information about available resources, (6) information about students, (7) information about learning the specific material in the instruction, (8) information that is explicitly about teaching the material in the instruction, (9) information that is implicitly about teaching the material in the instruction, usually in the form of a statement that some material should be included or that some kind of transaction should be used, (10) information

about the design task, and (11) personal information, such as an experience that the designer drew on or a personal preference about a way of teaching. The quantitative measure for types of knowing was the same as for subproblems, and multiple code-categories were applied to many segments of the transcripts.

The predominance of information that involved teaching about specific materials or with specific kinds of transactions corresponds to the predominance of work on the subproblems of determining the content and transactions of instruction. In comparisons between the two instructional tasks, more of the activity in the Operations designs involved information about the VST2000 and more of the activity in the Principles designs was about general information in science, as should have been the case. The Operations designs referred somewhat more to specific information about learning the instructional material, perhaps because the designers had just learned this material themselves. The Principles designs included more activity involving implicit information about teaching the materials and transactions to be included in the instruction. There were no evident differences between STEP graduates and beginning students in their profiles across the types of knowing, other than the overall greater length of the graduates' transcripts.

The typical longitudinal pattern of inferred types of knowing showed concentrations of use of subject-matter content and specific information about materials and transactions throughout the process. Some designers were concerned with general subject-matter information primarily at the beginning of their work on the problem, and some designers focussed on characteristics of the design task for some time at the beginning of their work.

Operations. We coded protocols for five operators: (1) proposing new material for the design, (2) modifying material that was in the design, (3) removing some material from the design, (4) including new information in the design space, and (5) commenting on the design by recapping, reflecting, evaluating, monitoring, or justifying material in the design.

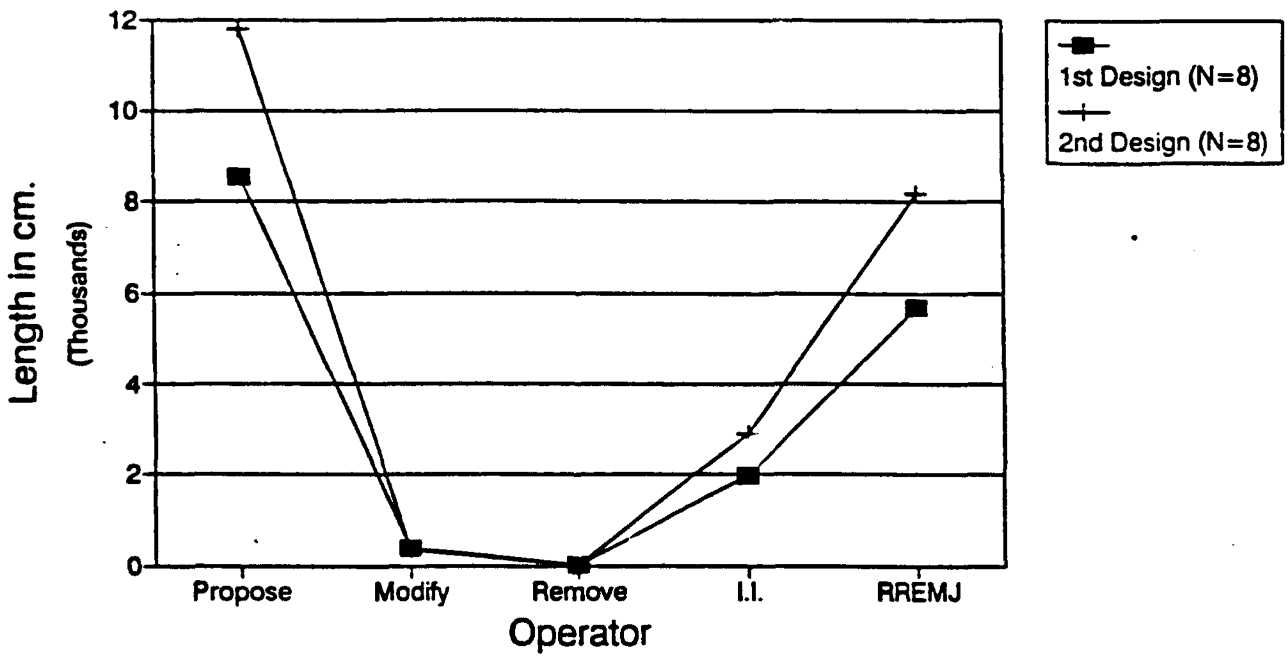

Figure 4. Lengths of transcriptions for operators.

The distribution of lengths of protocol segments is shown in Figure 4. Most distributions for subsets of the data were similar to Figure 4. One interesting variation was that the Propose operator took up somewhat less of the design activity in the Operations task than the Principles,

task, and the metadesign operators RREMJ were used somewhat more for the Operations task than the Principles task. In the longitudinal patterns, some designers used the Propose operator almost exclusively in the initial design and used RREMJ primarily when they reviewed the design, while other designers interspersed Propose and RREMJ during their initial design work.

A Model of Design Problem Solving

The rest of this paper reports results of an extended examination of four of the protocols obtained in the empirical study, focused on the organization of problem-solving activity. The model that we present is similar to models developed previously for design problem solving, notably by Hayes-Roth and Hayes-Roth (1978), by Simon (1973), and by Stefik (1981). The design problem space is characterized in terms of several levels of generality, and different functions are performed by distinguished hypothetical agents. These features are consistent with AI systems that have been developed for composing and planning instruction , such as the Instructional Design Environment (Russell, Moran, & Jordan, 1988), the Self-Improving Instructional Planner (Macmillan, Emme, & Berkowitz, 1988), and the Blackboard Instructional Planner (Murray, 1988).

The model describes a hypothetical design "committee" that can perform the range of activities in which a human designer engages. It organizes and makes sense of these activities in terms of a structured set of "actors" and their roles. This committee framework is flexible in that it allows the addition or deletion of members as needed to account for new data. This flexibility can be used to account both for stylistic differences between designers and for characteristic differences between various types of design tasks, for example, it might apply to instructional, architectural or engineering design.

We used the model to interpret think-aloud protocol data in terms of a set of categories for reducing the data to a more manageable form. The reduced data constitute a hypothesis about the organization of the designers' activities, the problem space in which they were working at any given time, the relative dominance of each type of actor, and the order of activities. The reduced data also can facilitate comparative analyses, for example, to show how designers differ from each other, or to identify additional actors and actions that are not included in the present model description, but which an individual designer might employ.

The model was developed by analyzing think-aloud protocols collected from four of the teacher-trainee designers who participated in our study as they each designed a piece of instruction. Two of the designers were just beginning their year-long course of study and two had just completed it, two were male and two were female, two were planning to be science teachers and two were teachers in other subjects, and two designers worked on the design tasks in each of the two sequences that we used in the study. The four protocols reflect a variety of approaches, and were selected to provide a range of data on which to develop the model.

OVERVIEW OF THE MODEL

As described previously, we see the primary task in design is one of construction rather than search. We identify two aspects of construction: to build the design itself, and to build the environment, or problem-space, in which the design is constructed. Our model begins with two problem-spaces to accommodate these two aspects of the task.

We conceptualize the system that creates the design as a committee of planners, each serving particular functions. Figure 5 depicts these planners and their associated problem spaces. This design committee comprises three subgroups: senior managers, middle managers and builders. The senior managers work on the task of problem-space construction. They determine

how to go about creating the design, provide information necessary for design construction, and monitor the design process. The middle managers guide the builders in constructing the actual design by coordinating the steps, advising on the design, and suggesting design possibilities. The builders are responsible for putting the actual pieces into the design at various levels of abstraction.

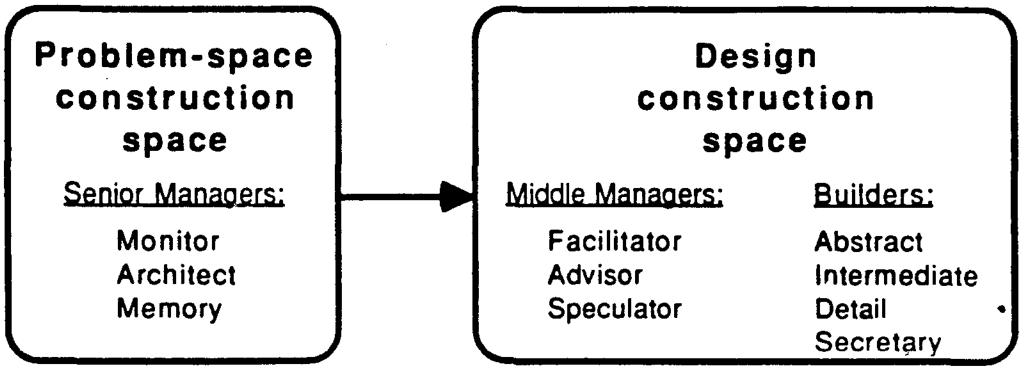

Figure 5. Design problem spaces and their associated actors.

Within each subgroup, various actors fill the different roles. The three senior managers are the Monitor, the Architect, and the Memory. The three middle managers are the Facilitator, the Advisor, and the Speculator. The builders are arbitrarily divided into three levels of abstraction: abstract, intermediate, and detail. In addition, a Secretary may record the decisions that the builders make. The next section describes the specific functions that these actors serves. Note that the model includes the actors and activities needed to describe the work of all four designers in our subsample. Individual designers did not necessarily employ every actor, and different designers might emphasize different functions of a particular actor.

ROLES OF ACTORS ON THE DESIGN COMMITTEE

Table 1 lists the design committee members and the responsibilities of each one. Several of the actors serve more than one function. These functions are distinguished in order to characterize the general contributions of each actor, but they may overlap. The important distinction is between the functions of different actors, not between the functions of a single actor.

The roles of committee members are described in detail, with specific examples, below. In the interests of conciseness, the examples are presented with minimal context. We sought instances that can stand alone, but recognize that there is some inherent ambiguity in decontextualized statements.

Senior Managers

The senior managers do not work on the design itself. They provide information and perform tasks that are prerequisite to the artifact construction work of the middle managers and builders. In trying to determine if a statement is made by a senior manager or by some other actor, the key question is: does the statement contribute directly to the artifact or not? If it does *not*, then the statement was made by a senior manager.

TABLE 1

Design Problem Spaces, Associated Design Committee Members, and Their Functions

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Problem-space Construction Space

Senior Managers: determine how to go about creating design

Monitor	1) guides design process; determines procedures; decides next planning task 2) keeps track of (monitors) design process
Memory	• spontaneously activates relevant memories
Architect	1) identifies constraints & goals given by E; defines task 2) adds or infers new constraints & goals 3) identifies or looks for missing constraints, goals or information

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Design Construction Space

Middle Managers: assist builders in creating the design

Facilitator	1) decides what part of design to work on, and whether to stop or continue; directs attention to different parts of design 2) looks for ideas of what to include; seeks next piece of design 3) keeps track of (reviews) the state of the design 4) adds to design agenda
Advisor	1) supplies (pedagogical) heuristics, beliefs, and suggestions 2) explains rationale, purpose, or effect of design decisions 3) assesses goodness of design 4) gives practical advice or comments on the design
Speculator	• considers possibilities for the design w/o including them

Builders: construct the artifact

Abstract	• determines the general approach to be taken (on large or small scale)
Intermediate	• decides topics; decides how long topics should take
Detail	1) includes details into the design; 2) describes classroom interactions, scenarios, or specific words to be used
Secretary	• records design decisions that have already been made (if a decision and recording occur simultaneously, the decision takes precedence, and the action is attributed to one of the builders above)

Monitor. The monitor both guides and monitors the design process. Notice that these jobs have to do with the *process* of design, and not with the design artifact itself. (Compare the functions of the facilitator, described below, which include similar activities aimed at the design artifact.)

Guiding the process may involve determining the procedures that will be used or deciding on the next planning task. Some examples of guiding the design process are: "I'm going to brainstorm some things, then decide how long I want this unit to be and how many days it would cover;" "I'm going to list the objectives;" and "I'll put the amount of time I would spend on each topic in parentheses." Note that theses examples plan future actions that will contribute to the design artifact. Those actions themselves will be performed, not by a senior manager, but by either a middle manager or builder.

Monitoring the design process involves keeping track of what one is doing. Some examples of monitoring are: "I'm going back and forth in explaining this right now;" "I'm stuck here;" "I'm starting to think on too many different levels right now;" and "I have to remember some stuff that I've learned."

Architect. The architect plays a key role in addressing the ill-structured nature of the design problem by adding structure to the task. This actor helps to shape the design construction space by introducing necessary information, including the goals and constraints under which the design will be built. The architect identifies goals or constraints included in the task assignment (which, in this case, would be design specifications that the researcher provided), infers or assumes new goals or constraints, and recognizes and seeks out information that is missing from the design space.

Identifying goals or constraints given in the assignment usually consists of repeating some task specification, such as: "So I'm designing or outlining an entire unit?" and "So, [I'm to design] a unit of instruction that can cover any number or days."

The most interesting of the architect's jobs is to add new goals and constraints to the problem space. This is the activity during which the architect adds structure to the ill-structured task. These constraints may be added by inference or assumption. Some examples are: "I'm assuming these will be 50-minute classes;" "my assumption is that the last unit was already on physics, so they already know about simple circuits;" "I'm interested in their developing the thinking processes;" and "I'm sure the Exploratorium has some [exhibit] like that."

The architect also recognizes when necessary information is missing from the problem space and tries to find it. Missing information may be from a variety of domains, e.g., design goals, content, available resources, and general knowledge. An example from each of these domains follows (the questions may be addressed to the self or to the researcher): "what is the bottom point of this? Am I trying to get them to think critically and figure this out on their own . . .., or do I just want them to be able to operate this?" "I can't remember what the other term was here. Local energy and . . . ;" "Could I use a computer tutorial such as this?" and "I'm . . . trying to think of forms of energy used in the world and trying to see what's missing from the machine."

Memory. The memory adds relevant, though not necessarily essential, information which the middle managers and builders can utilize. The information is provided spontaneously from the store of all information in long term memory. Some examples are: "the tutorial took me close to two hours;" "when I was first reading this [tutorial], I was a little bit confused because it looked like there were four items here. It took me a while . . . to see that there were three main branches of energy going into one motor;" and "since I'm not a science teacher, I'm not sure what is available in a typical high school."

Middle Managers

Middle managers provide information, direction, and suggestions that directly assist in creating the design, without adding to the artifact itself. One might distinguish their work from that of the builders by imagining the artifact as a physical object, consisting of components that have been added on. For any statement that concerns the artifact, the key question is: did the statement add a piece to the artifact? If it did not, it was made by a middle manager.

Facilitator. The facilitator coordinates the work of the other designers. It has four functions: to decide what part of the design the group will work on; to look for ideas of what to include in the design; to keep track of the state of the design; and to add to the design agenda (i.e., to decide what things the builders will need to include).

In deciding what part of the design to work on, the facilitator directs the attention of the other designers and decides whether to stop or continue work on a particular piece of the design. Here are some examples: "Okay, next topic;" "I'm going to leave that for right now and go into what I want to do with the latter part of the unit;" "Okay, now I'm looking back at your principles card;" and "I'm going to erase what I put for kinetic, because I want to expand a little on potential."

The following are some examples that involve looking for ideas of what to include in the design (the questions are addressed to the self): "Okay, now where do I go?" "How long should I make this unit?" "How would I break this down to teach something like that?" "I'm looking at the diagram now to see where I would go next. . . I'm looking to see if there is any particular topic that would make the most sense to go to next:" and "I'm trying to think of how they're going to show how well they've learned that."

Keeping track of the state of the design involves reviewing the design as it presently exists. (Compare the Monitor's function of keeping track of the design process.) Some examples are: "I'm looking at the days: Wednesday, Thursday, Friday. I've got three days here;" "so, we've defined things; we've motivated them; we've given the functions of each of the three systems, and we're starting to focus on the solar energy source . . . ;" and "we're almost done with the second week."

Adding to the design agenda is often associated in the data with reviewing the state of the design. In our data, there was little agenda-setting, but occasionally the designer mentioned something that should be included. Some examples follow (agenda-setting statements are printed in italics): "I haven't told them about those [forms of energy] yet,*which I would have to do;* " "I forgot to talk about . . . the startup switch . . . *I'm going to have to explain what that is;*" and"*things like what is a converter, what is a selector switch, what is a purifier . . . those kinds of basic things are going to have to be explained to them.*"

Advisor. The advisor provides the reasoning behind design decisions. Like the facilitator, it has four functions: to supply heuristics, beliefs and suggestions (which, in the case of instructional design, would have pedagogical content); to explain the rationale, purpose, or effect of design decisions; to evaluate the design; and to provide practical advice or comments. In practice, these functions may overlap, and an individual statement may subsume more than one function.

In providing pedagogical heuristics, beliefs, or suggestions, the advisor supplies the philosophical bases for making design decisions. These statements reflect the designer's understanding of how instruction ought to be accomplished. Some examples are: "[an advanced organizer] would be a very important thing for them to use;" "to be able to instruct someone else means that they [the students] really have to understand it themselves;" "that might stick in their

minds a little bit more if they can have a concrete example;" and "I think that it's important for them to understand how it's flowing first. I think they [would] get more out of . . . each one . . . if they knew what it was doing and where in the circuitry it's doing it."

The advisor also explains the rationale for design decisions or speculations. (In the following examples, explanatory statements are in italics.) "I'm contemplating whether it'd be worth it to demonstrate it to begin with, *just to get them to see what it's doing before I start describing it;*" and "I would use that to motivate them, *so that they could understand not only what is a motor, but where does it fit into their lives;*" and "I'll have them . . . do some kind of activity before I go on to the next one, *to make sure they're with me and they don't lose interest.*"

The advisor acts as a critic in assessing the goodness of the design. It may comment on aspects that are satisfactory or ones that ought to be changed: "Now it looks perfect--one day for each of these--because that's one week;" "that's going to make it unrealistic to split the groups for that long;" and "I'm feeling like all I'm doing now is lecturing . . . and I'm afraid I'm going to lose them if I spend the whole hour just lecturing."

Finally, the advisor may provide practical advice or comments on the design. For example: "[the decision] would depend on how many computers were available;" "the first illustration will take a little bit longer [to explain] because we'll be getting into specifics that they can relate to in the next two;" "I think some of this is just going to take patience and understanding because this is a complicated thing;" and "this really lends itself well to a discussion of the different forms of energy as proposed by the machine."

<u>Speculator</u>. The speculator considers possibilities for what to include in the design. These suggestions may be accepted, rejected, or ignored by the builders, who make the final decisions about what becomes part of the artifact. Speculator's statements offer pieces for the design, and so can look like builders' statements. In such cases, the context provides information about whether the piece was merely suggested or actually included in the artifact. Some examples of speculations are: "you could build a simple ramp and . . . maybe use matchbox cars . . . ;" "I'm thinking now about whether I should tell them about the differences between the wires;" "it would be possible to do some sort of advanced organizer before using the tutorial;" and "I wonder if I told them to work on the model on Friday, if it would be realistic to have them do that over the week-end and have it ready on Monday."

<u>Builders</u>

The main task of the builders is to construct the design artifact. In the process, they use information provided by the other actors. We define the builders on three levels of abstraction: abstract, intermediate, and detail. Because the builders deal at the level of the artifact, the tasks and examples we ascribe to the three types of builders are specific to instructional design. In another domain of design (e.g., architecture), one would expect that the distinction between levels of abstraction would still hold, but that the specific activities would be different. The decision to describe three (versus, say, two or four) levels of abstraction is arbitrary. We chose three levels because they fit the data reasonably well and seems to characterize the design artifact. To characterize different data or another level of tuning, one might choose more or fewer levels of abstraction.

In addition to the builders, there may be a secretary who records the decisions of the builders, but who does not suggest new pieces for the design. In our physical analogy of the artifact as object, the secretary would do the work of carrying the components from the builders and placing them on the artifact.

Abstract builder. The abstract builder determines the general approach the instruction will take, for example: "I'm going to follow the model of how I learned it;" "I'd start by following the format of the review box;" or "I'm going to break the information down into some basic categories and definitions."

Intermediate builder. The intermediate builder lists such things as topics, timing, and activities, without going into detail. Most planning was presented on this level. For example, "on Monday, I'd review the basic circuits and circuit diagrams;" "The next logical place to go after sources of energy is forms of energy;" and "now that I've gone through one, I would elaborate on each of the components--what each is and what it does." Some of these statements may sound like planning statements of the Facilitator. Here, as in other cases, the context provides information as to whether or not the statement actually added to the artifact.

Detail builder. The detail builder elaborates fine points of the design. For example: "I'll talk about . . . this power source . . . and [how] when the sun is shining, the energy is then taken in through the photo receptor cells, into the solar pack, and then it goes out the converter [and] into the selector switch;" "I'll use the example of a solar calculator;" and "it might be nice to ask anybody if they would like to take that as their project--to go to the Exploratorium and give an oral report on the different types of things they learned about different types of energy." The detail builder may get so specific as to describe anticipated classroom interactions and the actual words the instructor or students might say, for example: "maybe demonstrate rolling the ball down and hitting something else and say, 'how many other ways can you see potential energy turn into kinetic energy?' And they could come up with ways I'm sure that I would never think of--for example, instead of hitting something, they might put some type of spinner that sits over the track."

Secretary. The secretary does not actually build the design, but rather records decisions that have been made by one of the above builders. This role is included in the model to cover the single case in which a designer described writing down design decisions. Examples from the secretary included: "so first I'll write, 'introduce machine, describe parts;'" and "so I'll note 'Exploratorium' here." Occasionally, a decision was made and written simultaneously, in which case we attribute the action to one of the above builders rather than to the secretary.

APPLICATION OF THE MODEL

In applying the model to verbal protocol data, it is helpful to follow a structured sequence of steps. We mentioned some of these in the previous section. This section summarizes an organized set of guidelines for interpreting data in terms of the model.

The first step in applying the model is to break the protocol into units that represent single actions. We refer to these units as *statements*. The initial segmentation requires judgment on the part of the analyst as to what constitutes an action; these judgments can be modified later as application of the model proceeds.

The next step is to assign an actor to each statement. This assignment is facilitated by asking a series of general questions that narrow the options first to a particular category of actor, then to a specific actor. These questions are listed in Table 2.

TABLE 2

Sequence of Questions for Assigning Verbal Protocol Statements to Actors

1) Does the statement serve to define the problem-space or to construct the design?

2a) If to define the problem-space, which of the three senior managers is acting?
2b) If to construct the design, does the statement actually contribute to the design artifact?

3a) If yes to 2b, on what level of abstraction is the builder contributing?
3b) If no to 2b, which Middle Manager is acting?

The first question aims to determine which problem space each statement comes from--problem-space construction or design construction. According to the model, any statement that is relevant to the task belongs to one or the other of these spaces. If the statement serves to define the problem space, then the analyst can identify which senior manager is acting by referring to the roles listed in Table 1. If the statement serves to construct the design, the analyst should ask if it actually contributes to the design artifact itself, or if it is peripheral. If the statement is part of the artifact, then its level of abstraction indicates which builder is involved. If the statement is peripheral, then the analyst can identify which middle manager is acting, again, by referring to Table 1. To help confirm the assignment of an actor, if the actor has more than one action listed in Table 1, the analyst should determine which specific action is being performed.

AN ILLUSTRATION OF THE MODEL USING A VERBAL PROTOCOL

What does the model look like in practice? Below, we apply the model to an excerpt from the protocol of a novice designer we will call Sally. Sally had been in the teacher training program for about one month. She was creating a design to teach high school students to operate the VST. Table 3 shows the actors who participated in the first part of Sally's design. Senior managers are indicated in bold-face, middle managers in plain typeface, and builders in italics. The actions each participant performed can be determined by referring to Table 1. In the case of actors who can perform several functions, the action number in the third column of Table 3 refers to a numbered procedure from Table 1.

According to this interpretation, Sally began the task by attempting to construct the artifact, and immediately realized that she needed more information about the constraints on the task. Once she determined these constraints, she set off constructing the design again, with some suggestions from the middle managers.

In applying the model to Sally's entire design, we found that the model provides interpretations for the variety of actions in which she engaged. To illustrate this fact, Appendix I presents the first half of Sally's design, analyzed according to the actors who participate and the specific actions they perform. We will refer to this section of Sally's protocol again later in the paper.

TABLE 3

Actors Participating in First Part of Sally's Design

#	Statement	Actor (Action #)
1	How would I break it down to teach something like that?	Facilitator (2)
2	. . . are they going to use the computer at all, or . . . are they going to be learning to operate this? The same thing I did. It's not the actual--	**Architect** (3)
4	Then I just orally tell you how I'd set this	**Architect** (1)
5	I guess it doesn't matter what I tell you, but it's good to--	**Architect** (1)
7	I'm used to doing a presentation after I've thought about it.	**Memory**
9	I think what I would do first is give them a general overview of what it is.	*Intermediate Builder*
10	Basically sort of follow how I learned to do it, I guess.	*Abstract Builder*
11	Tell them . . . what it does, the general purpose of it, and why it's unique.	*Intermediate Builder*
12	. . . I'm contemplating whether it would be worth [it] to demonstrate it to begin with or not.	Speculator
13	Just to get them to see what it's doing before I start describing it.	Advisor (2)
14	And that, I haven't decided about.	Speculator
15	But I'll continue with the overview idea.	Facilitator (1)
16	So, I'd give them the general introduction about what it does and why it's so special.	*Intermediate Builder*
17	and of course the thing [VST] might be there. I'd be showing them the thing.	*Intermediate Builder*

GOAL STRUCTURE FOR INSTRUCTIONAL DESIGN

Previous sections have described the actors and the roles they play. In this section, we use the model to look at the structure of the goals that guide the design process, and compare the procedures of two very different designers. Based on analyses of their protocols, we identify two styles of design: *design by plan* and *design by feature*. Then we use this analysis to make some general statements about the goal structure for instructional design.

Table 4 below presents an excerpt from the protocol of a very organized designer whom we call Sid. Sid was a graduate of the teacher training program, and so had some experience teaching in a high school setting. In this excerpt, Sid was beginning a design to teach energy principles using the VST. (In the table, senior managers are listed in bold-face, middle managers in plain typeface, and builders in italics; action numbers in the third column refer to procedures from Table 1.)

TABLE 4

Actors Participating in the First Part of Sid's Design

#	Statement	Actor (Action #)
1	All right, this program is exactly the material I'd be able to use? This is the final form of the program?	**Architect** (3)
2	All right. It looks like you've got all different kinds of options because of the different types of energy sources: there's solar, there's vegetable matter so you can bring in biology, there's nuclear if you want to bring in fission or fusion. You can really expand. There are a lot of options there. And there's a whole different level of the machine itself, which are the principles that you've given me here.	Speculator
3	So it looks like this [principles card] would be the place to start; this would be the core of the lesson, with the tangents being little sub-topics that might lead into other units. By going back to this central theme in class, the principles card, by going back to that, you can do a sub-unit on, say, nuclear, or a sub-unit on solar, a sub-unit on vegetable-type power.	*Abstract Builder*
4	Okay, so, I'm designing an entire unit, sort of outlining?	**Architect** (1)
5	I'm thinking the best place to start would be to follow the format of the review box	*Abstract Builder*
6	and start out with familiarizing the students—	*Intermediate Builder*
7	Now I'm just starting a little outline on my pad	*Secretary*
8	familiarizing the students with the parts of the machine, showing each part separately and telling about it	*Intermediate Builder*

9	I would say one day's class for a general science course	*Intermediate Builder*
10	Maybe the first day would be introducing the machine itself, talking a little bit about the different . . . parts it has, and not really getting into any of the specifics of how the connections work.	*Intermediate Builder*
11	So first I'll put "I. introduce machine, describe parts"	*Secretary*
12	I think one class period should be fine for that.	Advisor (3)
13	Then, . . . once the kids are familiar with the parts, we could go into a little unit on energy sources . . . I think that's where I would go next.	*Intermediate Builder*
14	. . . and on my outline, I'll just call it "VST2000 Unit"	*Secretary*
15	and I'll put what I guess would be the amount of time I would spend on each topic in parentheses.	**Monitor** (1)
16	Secondly is sources	*Secretary*
17	. . . Roman numeral one, I wrote, "Introduce machine, describe parts." and then one day for that. And Roman numeral II., I just wrote "Sources of energy"	*Intermediate Builder*
18	and A., I'll put "Solar," B. Nuclear, C. Vegetable, and D. Other, which might not be included in the machine	*Intermediate Builder*
19	but I'd rather be complete and just use the machine to introduce as many topics as possible	Advisor (1)
20	Now it looks perfect—one day for each of these—because that's one week	Advisor (3)
21	Spend a day for each topic	*Intermediate Builder*
22	which, obviously we're just going to introduce, not go into any depth	*Intermediate Builder*
23	which is probably the best thing for this level anyway	Advisor(1)
24	And I think it would be good at this point . . . to assign a long-term . . . unit project to the class.	*Intermediate Builder*
25	So, I'm going to put, after Roman numeral II. "Sources of energy" I'm going to put "assign research project"	*Secretary*
26	Because already, since we're only going into limited depth, any of these topics lends itself to looking at it in more depth	Advisor (4)

The goals that Sid addressed in the above section of protocol are listed below in Table 5 (statement numbers from Table 4 are shown in parentheses). Table 5 indicates that Sid used a clear, well-organized approach. He began by clarifying his task and resources, by considering his design options, and by outlining a structure for his overall design. When he began the design itself, he worked in blocks, dealing with each block in a similar fashion. He first decided to begin a section. Then, within each section, he accomplished three things: he determined how long to spend on each part; he fleshed out the content; and he checked the adequacy of his decisions.

TABLE 5

Goal Structure for Initial Section of Sid's Design

- Clarify task constraints (1)
- Consider design options (2)
- Decide general plan for design (3)
- Clarify task procedures (4)
- Decide start point (5-8)
    - Determine timing for this section (9)
    - Flesh out topic (10-11)
    - Check adequacy of decisions so far/ for this section (12)
- Decide next topic/section (13-19)
    - Determine timing for this section (21)
    - Flesh out topic (22-23)
    - Check adequacy of decisions for this section (20)
- Decide next topic/section (24-26)

Sid's approach in this section of the protocol might be described as *design by plan*. He set out a general plan for his design (statement 3) before filling in the specifics, and when he did turn to specific units, he worked on them with an organized approach. We will see later, in the section on influences of external knowledge on design, that Sid made much use of outside knowledge structures provided by the computer tutorial and task instructions to organize his design.

In the goal structure outlined above, one can also see a hierarchical order of logic in Sid's decisions. He obtained needed information about the task before beginning it; he determined an overall structure for the design before filling in the details; he decided on a general topic before deciding how long a presentation would be; and he decided how much time to spend on a unit before determining what specific information to present within that time frame. He seemed to check the adequacy of his decisions as he made them. This, of course, is not the only logical order that a designer could choose.

The goal structure reveals how a particular designer approached the task. Sid was one of the more experienced designers in our subsample, had fairly good knowledge of the subject matter, and was willing to use existing information to aid in his design. These characteristics may have contributed to his organized approach. All designers will not necessarily be as well-organized. Sally was a case in point. Recall that she was a novice designer and that she had some difficulty remembering details of the VST subject matter (see statements 29 and 32 in Appendix I). Table 6 below presents a list of goals for Sally's protocol. (Numbers in parentheses refer to statement numbers from Appendix I.)

TABLE 6

Goal Structure for First Half of Sally's Design

- Break down information into teachable units (1)
- Clarify task constraints (2-3)
- Clarify task procedures (4-8)
- Decide start point (9-10)
    - flesh out topics (11, 15-16)
    - flesh out presentation method (12-14, 17)
- Consider content to include (18)
    - decide whether to include content (19)
    - Flesh out topic (19-21)
- Add more content (22-24)
    - revise sequence (22-23)
- Add pedagogical feature (26)
    - flesh out method and content (28-38)
        - get missing information about content (29-30, 32-33)
- Add more content (39-41)
    - decide sequence (40)
    - flesh out detail (43-47)
- Consider additional content (48-50)
    - revise sequence (48)
- Add more content (51-55)
    - decide sequence (53)
    - flesh out presentation method (57, 59)
        - determine constraints on task (56, 58)
- Determine goals of instruction (61-70)
    - consider different types of presentations for different goals (64, 67)

In contrast to Sid's *design by plan*, Sally's approach might be described as *design by feature*. Although she began her design similarly to Sid (and all the other designers), by obtaining information necessary to construct the design, she did not proceed by laying out a plan and progressing through the design in discrete units. Rather, she suggested items of information or activity as they occurred to her, and her subsequent design consisted of a list of topics, activities and pedagogical features, which she attempted to fit into a sensible whole. This approach to design is similar to the opportunistic planning described by Hayes-Roth and Hayes-Roth (1978).

Sally's strategy led to patching of her design—going back and inserting items (see statements 12, 22-23, and 48—which left the structure and feasibility of her design unclear. For example, it was not clear what would be included in the introduction versus later parts of the teaching, when she was going to tell the students about the differences between the two types of wires (statements 18-21), or how many days each item would cover. Ultimately, Sally ran into trouble when she realized that she did not know what the major goals of her instruction were. This lack of clarity in Sally's design suggests that the teacher implementing it would have a great influence on the instruction's ultimate form and outcome.

From the above analysis of the goals the designers addressed, we see that the goal structure (i.e., the goals set and their sequence) is knowledge-driven, but can be opportunistic, as well. For both designers, their decisions are influenced by the designer's knowledge of the task

environment, their ideas about the components of instruction, and their personal stylistic preferences for organization or opportunity.

Designers need certain information about the task environment before they can create a design. We suppose that this statement is true for all types of design, and that the specific information needed will depend on the particular task. Some of the information that our designers needed are an understanding of the task requirements, of the content of instruction, of the goals of instruction, and of the resources available. Sid and Sally both showed an understanding of this principle when they clarified the task constraints and procedures as they began their designs. When designers lack any of this information, they will hit a stumbling point in their design and have to obtain it, as indicated by Sally's statements numbered 29, 32, 56,58, and 61-70.

The goals that Sid and Sally addressed reveal the components that they thought ought to be included in their instructional designs. These components are content and activities (both general and specific), order of presentation, timing, and presentation methods (including materials). Different designers may emphasize different components. Sid included more of the listed components, and included them more consistently, than Sally did.

Designers also possess their own styles for addressing the task, which may depend on their level of experience with design, knowledge of the content, and personal preferences for how to construct a design. We have seen two styles: *design by plan* and *design by features*. Analysis of additional protocol data would be likely to reveal others. The point is that a designer's preferred style will influence the goals he or she addresses, and the order in which he or she addresses them.

Knowledge Used in Instructional Design

This section examines types of knowledge that were used in relation to the functional roles identified in the model, and the role of knowledge in creating the design.

Each actor needs certain types of knowledge in order to perform its function. Whereas the functions that the actors serve are general and can apply to a variety of design tasks (see Table 1), the knowledge the actors use is specific to the type of design being created—in this case, instructional design. This section describes some types of knowledge that each actor might use in designing instruction, and discusses the sources of that knowledge. Then, it proposes a basis on which the pedagogical content knowledge contained in the design is generated. In a later section, we will analyze specific influences of knowledge on design activity.

TYPES OF KNOWLEDGE USED BY ACTORS

Table 7 lists some types of knowledge that the actors would use in creating a design for instruction. This list characterizes the range and main types of information that different actors would use, but is not meant to be exhaustive. The types of information were determined by analyzing the role of each actor and its relationship to the knowledge types that we identified in analyzing the 16 design protocols that we obtained (see Figure 3).

TABLE 7

Knowledge Used by Design Committee Members

Problem-space Construction	
Monitor	• current design process • model of instructional design process
Memory	• content, i.e., VST & science • personal experiences and characteristics as teacher and learner • designer's long term memory
Architect	• design task requirements, including goals and constraints • teaching context, including available resources & students
Design Construction	
Facilitator	• model of instructional components • design task requirements • current state of design
Advisor	• general pedagogical heuristics • pedagogical content • teaching context, including available resources & students • model of good instruction • current state of design
Speculator & Builders	• model of instructional components • content, i.e., VST & science • pedagogical content • teaching context, including available resources & students • current state of design
Secretary	• design decisions made by builders

The monitor, who keeps track of the design process, employs information about that process, including knowledge of the procedures as they take place and a model of the course that the process ought to follow—i.e., an instructional design schema. The memory may retrieve any information from the designer's long-term store, but is especially likely to employ information concerning the instructional content and the designer's personal experiences as a teacher or learner. The architect, who is the primary builder of the space in which the design is constructed, has knowledge of constraints on the task, including task requirements and the setting in which the instruction will take place. The facilitator, who coordinates the design construction, employs

information about the requirements of the task, the current state of the design, and a model of the components that instruction ought to include—i.e., an instructional schema (compare instructional design schema, described above). The advisor, who provides pedagogical advice and evaluates the design, possesses knowledge of guidelines for teaching in general (pedagogical heuristics) and for teaching this material in particular (pedagogical content), beliefs about the setting in which instruction will occur, an evaluative model of what constitutes "good" instruction, and knowledge of the current state of the design. The speculator and builders perform similar functions in creating the design and use the same types of knowledge, i.e., a model of components to be included in instruction (instructional schema), knowledge of the content being taught and how to teach it, information about the setting in which instruction will occur, and the current state of the design. The secretary records decisions made by the builders, and so needs only information about those decisions.

The examples below illustrate most of the types of knowledge listed in Table 7. The reader can find the context for these examples in the protocols in Table 4 and Appendix I. Note that the designers may use several types of knowledge in any given statement, and the following examples often contain more than one type. Also note that, in practice, knowledge may be either explicitly stated or implied. Examples of both types appear below, with explanations provided for examples in which the knowledge is implied.

Model of design process: "I have to decide what my focus is" (Appendix I, statement 63)

Personal experience: "I'm used to doing a presentation after I've thought about it," (Appendix I, statement 7). "Basically [in teaching, I would] sort of follow how I learned to do it." (Appendix I, statement 10; indicates an implicit understanding of how the designer learned).

VST2000: "like a car, it needs a source of its own power to get going" (Appendix I, statement 19). "Give them a table and have it set up for them. One column for each unit, what kind of energy it produces, what it needs--source of raw energy." (Appendix I, statement 28; indicates implicit understanding of VST units and energy requirements.)

Science: "[Y]ou've got all different kinds of options because of the different energy sources. There's solar; there's vegetable matter, so you can bring in biology; there's nuclear if you want to bring in fission or fusion" (Table 4, statement 2).

Design Task: "Are they going to be using the computer at all, or are they going to be learning to operate this?" (Appendix I, statement 2). "Then I just orally tell you how I'd set this" (Appendix I, statement 4). "How would I break it down to teach something like that?" (Appendix I, statement 1; indicates implicit understanding that the task is to teach).

Context--available resources: "I don't know whether I'd have 30 computers" (Appendix I, statement 56).

Context--students: "[This design] is probably the best thing for this level [of student] anyway" (Table 4, statement 23).

Instructional components: "And I think it would be good at this point . . .to assign a long-term . . . unit project to the class" (Table 4, statement 24).

Pedagogical heuristics: "I'd rather be complete, and just use the machine to introduce as many topics as possible" (Table 4, statement 19). "It'd be good to give each kid a feel, to try to move the switch" (Appendix I, statement 57). "I think what I would do first is give them a general overview of what it is" (Appendix I, statement 9; indicates implicit belief that instruction should begin with general information).

Pedagogical content: "I'm thinking the best place to start would be to follow the format of the review box" (Table 4, statement 5).

Model of good design: "Now it looks perfect--one day for each of these--because that's one week." (Table 4, statement 20).

SOURCES OF KNOWLEDGE

We distinguish two major sources of knowledge—internal and external. Internal information is retrieved from the designer's memory. External information is obtained from sources outside the designer's mind, such as notes, diagrams, the computer tutorial, or the experimenter. Internal knowledge consists of two types of information: pre-existing and generated. Pre-existing knowledge is the information and beliefs stored in memory that an individual brings to the task. It includes such things as knowledge of content, pedagogy, and personal experiences. Generated knowledge is *ad hoc* information, created on the spot to meet a particular need. Some examples of generated knowledge are information about the state of the design, the current design process, and designer-supplied goals and constraints. A particularly interesting example of generated knowledge in these data is pedagogical content knowledge. The next section explores the generation of pedagogical content knowledge in these data. In a later section, we will look at the influences of various types of knowledge on instructional design.

GENERATED PEDAGOGICAL CONTENT KNOWLEDGE

Pedagogical content knowledge consists of information about how to teach the particular content under consideration. It is the type of knowledge represented in the design artifact itself. In the present data, pedagogical content knowledge is primarily generated during the design process. Note that pedagogical content knowledge does not necessarily have to be generated during design; experienced designers could possess pedagogical content knowledge as part of their expertise, for example, in how to teach history or math. However, this study provides an unusual opportunity to observe pedagogical content knowledge being generated, because it was structured so that the participants were designing instruction about content that they had never taught before.

This section focuses on how pre-existing knowledge is used in generating pedagogical content knowledge. In our view, pedagogical content knowledge is created using pedagogical knowledge, content knowledge, personal experiences related to the content, and knowledge of the teaching context. The process by which it is generated might be considered analogous to carrying on a conversation. In that case, the artifact (that is, the conversation) is created as the parties speak, and the particular form it takes derives from the speakers' implicit understanding of how to communicate, their knowledge of the subject matter being discussed, their personal feelings and experiences related to that subject matter, and the context of the conversation. In the same way, the design artifact is created using an implicit understanding of how to teach, knowledge of and experience learning the subject matter to be taught, and the context in which the teaching will occur.

We will use Sid's protocol to explore the relation between existing and generated knowledge. As indicated previously (see Table 7), the builders, speculator and advisor are the actors most likely to use pedagogical content knowledge. Looking at the section of Sid's protocol presented in Table 4, one can see that, indeed, the statements made by these actors were the ones that contained knowledge about how to teach this particular material. Many pieces of knowledge contributed to the pedagogical content statements in Sid's protocol. Table 8 below suggests some specific beliefs and information that seem to have played a role. Statement numbers from Sid's protocol in Table 4 and knowledge-types corresponding to each belief are indicated.

TABLE 8

Specific Information Contributing to Sid's Pedagogical Content Knowledge, with Knowledge Types and Statement Numbers (from Table 4)

Statement #	K-Type	Information and Beliefs
2, 3	content	types of energy sources, VST machine, and scientific principles;
3	pedagogy	begin with an overall structure for the instruction;
5	learning exp	the tutorial review box presents these topics in a sensible order for teaching;
5	ped content	"
6, 8	learning exp	the tutorial begins by familiarizing the learner with the parts of the machine
9	pedagogy	knowledge of how much material can be covered in one day
9	teach context	how much material can be covered in this type of classroom with this type of student;
10	pedagogy	in the beginning, give a general presentation; don't get too specific;
10	content	VST parts and connections;
13	pedagogy	students should learn one lesson before beginning a new one
17, 18	pedagogy	information should be presented hierarchically ;
18	content	three energy sources are used in the VST;
18	content	other energy sources are used in the world
19	pedagogy	be complete
19	pedagogy	use available resources to introduce as many topics as possible
20, 21	pedagogy	it is good to cover one topic per day
20	teach context	an academic week consists of five days
20	pedagogy	it is good if lessons fit into a five-day/one-week package;
22	pedagogy	in one day, you cannot get into too much depth on a topic
23	teach context	it is best to begin by giving this level of student only an introduction to the material;
23	pedagogy	"
24	pedagogy	it is good to have a variety of activities;
24	pedagogy	it is good to make students responsible for doing a project on their own;
24, 26	pedagogy	it is good for students to pursue their particular interests in more depth;
26	teach context	class time doesn't allow for looking at all valuable topics in sufficient depth

The knowledge types represented in Table 8 span the four types from which we claim pedagogical content knowledge is derived, that is, knowledge of pedagogy, content, teaching context and learning experience. Note that the third piece of information listed in Table 8—that the tutorial's review box presents information in an sensible order for teaching—is identified as pedagogical content knowledge (as well as learning experience). Even though we cannot identify the specific pieces of information on which this information is based, it is likely that the knowledge was generated on the spot because the designers were not told prior to being presented with the

task that they would be designing instruction. This example seems to indicate the spontaneity with which pedagogical content knowledge can be generated.

Next, we want to show how the above knowledge is related to the artifact. The following analysis describes how each piece of knowledge listed in Table 8 above relates to the pedagogical content knowledge generated in the excerpted section of protocol.

Sid began his design by listing different options for what to present in his instruction (statement 2). This required knowledge of the content: energy sources, scientific principles and the machine itself. Next he chose a general structure for the content, which we assume was based on a pedagogical belief that it is good to begin with an overall structure. Statement 5 reflected a decision to follow the sequence of topics presented in the review box of the tutorial. We infer that this decision was based on the belief that the review box presents information in a sensible order for teaching. The next step (statements 6 and 8) was to flesh out that decision, explaining the first topic and how it would be presented. This decision was likely based on the information presented in the tutorial. The subsequent decision (statement 9) concerned how much material can be covered in one day (with the implicit limitations of the teaching context: this type of classroom and this type of student). This was followed by a further fleshing out of the first day's presentation (statement 10), based on the apparent belief that, in the beginning, it is best to give a general presentation and not get too specific.

Sid then made an implicit judgment that the first topic had been covered sufficiently, and decided to go on to the next topic (statement 13). In deciding that the next unit will be on particular energy sources (statements 17 and 18), he departed from his original plan to follow the sequence of topics in the review box (energy sources are not listed in the review box), and determined what information he thought it was best to teach next. The question arises: where did this decision come from? As will be described later, these topics are near the top of a hierarchical understanding of the VST. We infer that the decision to cover the energy sources next was based on the designer's understanding of the VST combined with the implicit pedagogical belief that it is best to teach according to a hierarchical knowledge structure.

Sid knew that three types of energy sources are included in the VST, and decided to spend a day on each one, with an extra day for energy sources that are not included in the machine (statements 18 and 21), simultaneously assessing that his design was good (statement 20). We infer that these decisions were based on an understanding of the school calendar and the beliefs that it is best to cover one topic per day and it is good if the lessons fit into a neat one-week package. Sid again used his judgment concerning how much material can be covered in one day, and reinforced this decision with the belief that this level of student only needs an introduction to the material (statements 22 and 23).

Finally, Sid decided to insert a project assignment in which the students would go into one topic in more depth (statements 24 and 26). The beliefs leading to this decision might be stated in a variety of ways: it is good to have variety of activities; it is good to make students responsible for doing a project on their own; it is good for students to pursue their particular interests in more depth; and class time doesn't allow looking at all valuable topics in depth.

In sum, this analysis shows that four types of pre-existing knowledge can be used to generate pedagogical content knowledge: knowledge of pedagogy, content, teaching context and learning experience. It also supports the claim that the builders, speculator and advisor are the actors most likely to use pedagogical content knowledge.

Influences of Knowledge on Instructional Design

The knowledge a designer possesses influences the goals that are set and how those goals are accomplished. This section discusses influences of pre-existing, generated, and external knowledge on both the design process and design artifact.

INFLUENCES OF PRE-EXISTING KNOWLEDGE

General considerations suggest that certain pieces of pre-existing knowledge influence the outcome of design. For example, the designer's model of instructional components determines what the designer will include; the designer's model of good design sets standards for how the design will be evaluated; and pedagogical heuristics guide how the designer will structure the content, presentation, sequencing, and timing of the instruction. In fact, we infer the content of these types of information from the designer's activities. For example, we identify the pedagogical heuristics a designer used by analyzing the protocol data.

To address some questions about the role of pre-existing knowledge in design without depending on inferences based on design protocols, we conducted an analysis of VST2000 knowledge in design. VST information was used extensively in the design task, and we could derive an elaborated description of it from the tutorial materials, without making inferences from the protocol data. We assumed a semantic network structure to the information and developed a computer model that represents VST2000 knowledge.

SEMANTIC NETWORK REPRESENTATION OF THE VST2000

The semantic network representation of the VST 2000 knowledge was constructed by a computer program from a list of propositions. These propositions were obtained through an analysis of the tutorial materials. Each proposition consists of a node-relation-node triplet and a direction indicator that provides information about how to order the nodes within the proposition. The resulting semantic network does not retain the structure of the tutorial from which the designers learned about the VST—that is, it does not contain the same order of topics, exercise questions, or structure of the descriptive text. Rather, it is a hypothetical representation of the information that designers could have obtained from the tutorial instruction. A portion of the semantic network generated by our computer program is represented diagramatically in Figure 6. This selection represents about 10% of the total network generated.

One can calculate the distance between any two nodes in the network by counting the number of relational links that must be followed to connect the two nodes. The distance from the root node (in this case, *VST 2000*) to a particular node indicates the level of that node in the network. As Figure 6 indicates, the network has a hierarchical structure; nodes lower in the network are components or descriptions of higher-level nodes.

RELATIONSHIP OF SEMANTIC NETWORK TO DESIGN

An examination of the protocol data in conjunction with the semantic network model revealed several hypotheses concerning how knowledge in the semantic network relates to the design. These hypotheses are:

- High-level knowledge (adjacent to the root node) is presented first in instruction;
- Information near the most recently used node is often included next;
- Low-level knowledge (far from the root node) is often omitted from the design;

- Similarity between sections of the network is used to advantage in the design;
- Incomplete knowledge leads to a breakdown or refocusing of design activity; and
- Design process is not necessarily either breadth-first or depth-first.

The first four hypotheses involve the structure of the design artifact relative to the structure of the semantic network. The first three taken together indicate that information about the VST2000 in the designs tended to reflect the semantic network structure generated by our computational model, rather than, for example, the didactic structure of the tutorial or the spatial structure of the schematic diagram of the VST. The last two hypotheses involve the design process relative to the semantic network. We will describe each hypothesis in turn, citing an example for each.

Higher-level knowledge. It is well-recognized that higher-order information in a semantic network is typically accessed first when people recall information from memory (e.g., Kintsch, 1974). Stevens and Collins (1977) found that higher-order information in a semantic network was typically presented first by tutors. Our data indicate that higher-order information also was presented first in instructional design—that is, knowledge from nodes adjacent to the root node in the network were among the first to be presented. For example, one of the first things Sid did was to describe the different types of energy sources of the VST2000 (Table 4, statement 2). The nodes describing these energy sources (solar, vegetable matter, and nuclear energy sources) are directly linked to the root *VST 2000* node in Figure 6.

Adjacent knowledge. Knowledge from nodes near the most recently used node were often included in the design next. The structure of the semantic network requires that adjacent nodes contain related knowledge. In fact, many branches of our network contain groups of nodes and relations that describe the features, sub-parts, and capabilities of a particular VST 2000 component. When a designer included a VST 2000 component in the design, he or she often include information related to that component from adjacent nodes.

Lower-level knowledge. Knowledge from nodes at low levels in the network is often left out of the design. In some cases, knowledge from these lower level nodes was simply not mentioned, but in other cases it was explicitly excluded from the design.

Similar knowledge. Designers sometimes borrowed pieces of the design about one part of the VST and applied them to a different part if the representation of the knowledge for those two parts was similar. For example, Sally noted that the VST 2000 power units are similar: "the units are basically the same . . . I think if you just teach one, what you learn on one you can extrapolate to the other two relatively easily." Her recognition of the similarity between the units allowed her to simplify her design task by concentrating on teaching the operation of one unit in detail and applying that solution to similar parts.

Incomplete knowledge. When the designer's representation of the knowledge in the network was poorly elaborated or incomplete, a breakdown or refocusing of the design activity occurred. We first identified this phenomenon in our analysis of the goal structure in the previous section. The principle is reiterated when we consider the semantic network in relation to the protocols. For example, Sally (Appendix I, statements 32-34) was unable to remember the names of the switch settings. We infer that her semantic network was weak in this area. She could expend effort to remember these details, which would lead to a momentary breakdown in design activity as she focused on obtaining that information, or she could ignore the missing information and continue her design without it (as she did in statement 35).

Sequence of design process. Though the design artifact itself tends to reflect the structure of the semantic network, the design process does not necessarily do so. When designers included knowledge from a particular node in the network, they had a variety of choices about what to discuss next. They could explore nodes that are subordinate, superordinate, on the same level as, or distant from the node just discussed. The decision could depend on what they had covered so far, the integrity of the knowledge in memory, how interesting or important the information was to the design, and other factors. The design process can take a complicated path through the network, and does not necessarily follow either a breadth-first or depth-first expansion.

To illustrate this situation, when Sally first discussed the VST 2000, she described the differences between the two kinds of wires on the machine (Appendix I, statements 18-22). In the semantic network, the nodes describing the wires are actually two levels from the root node, so the order in which she discussed the VST2000 in her design *process* did not match the semantic network representation. However, in statements 22-23, Sally indicated that the instruction itself would describe the different kinds of energy used by the units (which are closer to the root node) before it described the wires. Therefore, the structure of her design *artifact* more closely matched the structure of the semantic network than the design process did.

INFLUENCES OF GENERATED KNOWLEDGE

The primary influence of generated knowledge on design can be summarized as: what the designer has already done affects what he or she will do in the future; or more simply: where one goes depends partly on where one has been. Generated knowledge of the current design state and of the decisions made by actors have an important influence on the subsequent content that is included and tasks that are accomplished. This is what gives the designs coherence, and allows one topic to flow into another. Sid's and Sally's protocols both demonstrate this principle: "Then, . . . once the kids are familiar with the parts, we could go into a little unit on energy sources . . . I think that's where I would go next," (Table 4, Statement 13); and ". . . actually, at this point, I've gone through one, and then I would elaborate on each of these components . . . what the unit is and what it does . . . orient them to each particular component on the flow," (Appendix I, statements 51-52).

Some tasks cannot logically be completed until certain knowledge has been generated. For example, one cannot evaluate the design until it is complete enough to bear scrutiny. Also, certain decisions naturally lead into other decisions. For example, the designer generates constraints for the task that guide the subsequent parts of the design. This is demonstrated in Sally's protocol when she decides that it is possible for each student to have a computer, and then adjusts her design to include students working individually on the machines (Appendix I, statements 56-59).

INFLUENCES OF EXTERNAL KNOWLEDGE

The two main functions of external knowledge are to provide information the designer is lacking (e.g., about the requirements of the design task or features of the VST2000), and to suggest ideas for the design artifact (e.g., about structure, content, or sequencing of the design). In our study, the external sources of information were primarily the interviewer, the computer tutorial, notes the designer had made while learning about the VST 2000, and a *principles card*, which was presented as part of the task instructions and which listed energy principles that designers could consider including in their designs. The precise way in which external knowledge was used depended, in part, on its form and structure. Below, we present examples from the data that demonstrate how knowledge from external sources influences design activity.

Supply Missing Information about the Task Environment. When designers lacked necessary information, they often went to external sources to obtain it. Identifying and obtaining

missing information is the third function of the Architect, listed in Table 1. The types of information obtained usually concerned the requirements of the task and the details about the VST 2000. When designers needed information about task requirements, they turned to the interviewer for clarification. In fact, all of the designers began the task this way. Sid's and Sally's protocols illustrate this (see Appendix I, statements 2-3 and Table 4, statement 1). When designers needed information about the VST 2000, they might turn to a variety of sources. In the following excerpt, the designer used both a diagram from the computer tutorial and the interviewer to clarify the functioning of the VST:

> Can you review [for] me again on this . . . diagram, where it says the power—Okay, it means that when this is on . . . it goes to pick up—well, for example, where is this power coming from? (Designer G4B, speech 5.8)

Suggest Ideas for the Design Artifact. Designers used external knowledge in creating the design artifact in several ways: to structure their designs, to cue themselves about information to include in their designs, and to incorporate knowledge directly into their designs.

Sid used the principles card to broadly structure his design (Table 4, statement 3). Later, he compared the principle's card to his design to determine what he had covered and where he needed to go:

> Okay, now I'm looking back at your principles card. We sort of touched on storing energy a little bit, because that would come under the lesson on potential—not how it's stored, but what stored energy is and what can be done with it. Kinetic sort of touches on extracting stored energy; converting has been introduced. But we haven't gone into transporting, and we haven't gone into purifying. (Sid, statements 83-84)

Within the overall structure defined by the principles card, Sid used other external information to make local decisions about his design. In the following example, he used a diagram of the VST 2000 and the topic review box, both of which were part of the computer tutorial, to determine his next move:

> I'm looking at the diagram now to see where I would go next. I'm looking at the review box . . . to see if there's a particular topic that would make the most sense to go to next. I'm looking for any kind of relation between the energy sources and the machine. (Sid, statement 30)

Later, he referred to the review box to seek a title for his current topic, and the review function of the tutorial to suggest information that he ought to include in his instruction:

> I'm looking at the review box to see if there would be a good title to call this. There are a lot of topics in the review box: extracting energy, transporting it, forms, converting, purifying—what I'm going to do is I'm going to look at it right now and see if it's good, and then go to the forms of energy [in the tutorial instruction]. The screen says "it uses four forms of energy: raw, impulse, purified, and mechanical. In addition, local electricity must be supplied." I haven't told them about those forms of energy yet, which I would have to do, maybe. (Sid, statements 66-71)

Sometimes designers used external information to remind themselves about features of the VST while simultaneously incorporating that information into the design. In the following example, Sally used her own notes to refresh her memory about the energy flow in the VST, while proposing to use this diagram as part of the instruction:

> But I'm going to give them this flow chart I did: the unit, you get the raw energy, it goes to the converter, it's impulse energy, and then it goes to I-switches, it goes to the purifier—and give them this little flow chart to follow. And then how it goes from the I-switches to the O-switches and then it enters the motor, which indicates what it does...and say that that's an indication [that] mechanical energy's being produced. (Appendix I, statement 46)

Conclusions

The process of design is both data-driven and goal-driven, and both utilizes and is shaped by several sources of knowledge and information. Our discussion of instructional problem solving is similar to other information-processing analyses of design problem solving, involving differentiated problem subspaces and multiple functional roles.

This analysis of instructional design by relative novices extends the information-processing literature. Most of the previous analyses of problem solving in tasks of arrangement and design either used highly constrained tasks, such as cryptarithmetic (Newell & Simon, 1972) and planning a sequence of errands (Hayes-Roth & Hayes-Roth, 1976), or focused on processes that require a great deal of domain-specific expertise (Jeffries et al., 1981; Pirolli & Berger, 1991; Stefik, 1981; Ullman, et al., 1988; Voss et al., 1983). In our study, the relatively open-ended and large task of instructional design was performed by relative novices who had only a few hours of formal training in instructional design (for constructing lesson plans) and had less than two hours of study in the subject-matter domain of the VST2000. The framework that we used successfully to interpret our data is generally consistent with the results of previous research, and therefore adds a segment of the scientific problem space to which the information-processing approach has been applied.

The quasi-social nature of our characterization is metaphorical, of course, but it facilitated our understanding and interpretation of our data. We find it intriguing to speculate that the metaphor of social interaction may have a substantive basis for the analysis of individual cognitive activity. Most complex cognition occurs in settings of collaboration, and the patterns of activity that people learn in those settings could well shape the processes of problem solving that we engage in when we work as individuals.

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References

Akin, O. (1984). An exploration of the design process. Developments in Design Methodology (pp. 189-207). New York, NY: Wiley.

Allen, C. (1988). Situated designing. Unpublished masters thesis, Carnegie-Mellon University, Pittsburgh, PA.

Bereiter, C., & Scardamalia, M. (1987). The psychology of written composition. Hillsdale, NJ: Lawrence Erlbaum Associates.

Ericsson, K. A., & Simon, H. A. (1984). Protocol analysis: Verbal reports as data. Cambridge, MA: MIT Press.

Getzels, J. W., & Csikzentmihalyi, M. (1976). The creative vision. New York, NY: Wiley.

Goel, V., & Pirolli, P. (1991). The structure of design problem spaces (Report No. DPS-3). Berkeley, CA: University of California, School of Education.

Greeno, J. G., & Berger, D. (1987). A model of functional knowledge and insight (Tech. Rep. No. GK-1). Berkeley, CA: University of California, School of Education.

Greeno, J. G., & Berger, D. (1990). Knowledge about system components and functions in diagnostic problem solving (Tech. Report). Stanford, CA: Stanford University, School of Education.

Greeno, J. G., Korpi, M. K., Jackson, D. N., III, & Michalchik, V. S. (1990). Processes and knowledge in designing instruction (Tech. Report). Stanford, CA: Stanford University School of Education.

Hayes, J. R., & Flower, L. S. (1980). Identifying the organization of writing processes. In L. W. Gregg & E. R. Steinberg (Eds.), Cognitive processes in writing. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hayes-Roth, B. & Hayes-Roth, F. (1976). Cognitive processes in planning (Report No. R-2366-ONR). Santa Monica, CA: Rand Corporation.

Jeffries,R., Turner, A. D., Polson, P. G., & Atwood, M. E. (1981). The processes involved in designing software. In J. R. Anderson (Ed.), Cognitive skills and their acquisition (pp. 255-283). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kant, E. (1985). Understanding and automating algorithm design. Proceedings of the Ninth International Joint Conference on Artificial Intelligence (Vol. 2, pp. 1243-1253).

Kant, E., & Newell, A. (1983). An automatic algorithm designer: An initial implementation. Proceedings of AAAI-83 (pp. 177-181).

Kintsch, W. (1974). The representation of meaning in memory. Hillsdale, NJ: Lawrence Erlbaum Associates.

Korpi, M. K. (1988). Making conceptual connections: An investigation of cognitive strategies and heuristics for inductive categorization with natural concepts. Doctoral dissertation, Stanford University.

Macmillan, S. A., Emme, D., & Berkowitz, M. (1988). Instructional planners: Lessons learned. In Psotka, J., Massey, L. D., & Mutter, S. A. (Eds.), Intelligent tutoring systems: Lessons learned (pp. 229-256). Hillsdale, NJ: Lawrence Erlbaum Associates.

Murray, W. R. (1988). Dynamic instructional planning in the BB1 blackboard architecture (Tech. Report). Santa Clara, CA: Central Engineering Laboratories.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Pirolli, P., & Berger, D. (1991). The structure of ill-structured problem solving in instructional design (Report No. DPS-5). University of California, Berkeley, School of Education.

Reigeluth, C. M. (Ed.), Instructional-design theories and models: An overview of their current status. Hillsdale, NJ: Lawrence Erlbaum Associates.

Reitman, W. R. (1965). Cognition and thought: An information-processing approach. New York, NY: Wiley.

Russell, D. M., Moran, T. P., & Jordan. D. S. (1988). The instructional-design environment. In Psotka, J., Massey, L. D., & Mutter, S. A. (Eds.), Intelligent tutoring systems: Lessons learned (pp. 203-228). Hillsdale, NJ: Lawrence Erlbaum Associates.

Simon, H. A. (1973). The structure of ill-structured problems. Artificial Intelligence, 4, 181-201.

Stefik, M. (1981). Planning with constraints (MOLGEN: Part 1). Artificial Intelligence, 16, 111-140.

Stevens, A. L., & Collins, A. (1977). The goal structure of a Socratic tutor. Proceedings of the National ACM Conference (pp. 256-263). Association for Computing Machinery.

Ullman, D. G., Dietterich, T. G., & Stauffer, L. A. (1988). A model of the mechanical design process based on empirical data. University of Oregon, Eugene, OR.

Voss, J. F., Greene, T. R., & Penner, B. C. (1983). Problem solving skill in the social sciences. In G. H. Bower (Ed.), The psychology of learning and motivation: Advances in research and theory (Vol. 17, pp. 165-213). New York, NY: Academic Press.

Appendix I

Actors Participating in First Half of Sally's Design

The table below shows the actors who participate and the actions each performs. Senior managers are indicated in bold-face, middle managers in plain typeface, and builders in italics. Action numbers in the third column refer to the numbered procedure from Table 1 in the main body of the paper, that each actor seems to be performing.

#	Statement	Actor (Action #)
1	How would I break it down to teach something like that?	Facilitator (2)
2	. . . are they going to use the computer at all, or . . . are they going to be learning to operate this? The same thing I did. It's not the actual—	**Architect (3)**
3	Are they going to have it . . . so you could have them actually doing stuff?	**Architect (3)**
4	Then I just orally tell you how I'd set this	**Architect (1)**
5	I guess it doesn't matter what I tell you, but it's good to—	**Architect (1)**
6	Yeah, as I do it, not . . . just any idea that I come up with.	**Architect (1)**
7	I'm used to doing a presentation after I've thought about it.	**Memory**
8	Present it as I do it. Not present it, but as I think about it.	**Architect (1)**
9	I think what I would do first is give them a general overview of what it is.	*Intermediate Builder*
10	Basically sort of follow how I learned to do it, I guess.	*Abstract Builder*
11	Tell them . . . what it does, the general purpose of it, and why it's unique.	*Intermediate Builder*
12	. . . I'm contemplating whether it would be worth [it] to demonstrate it to begin with or not.	Speculator
13	Just to get them to see what it's doing before I start describing it.	Advisor (2)
14	And that, I haven't decided about.	Speculator
15	But I'll continue with the overview idea.	Facilitator (1)
16	So, I'd give them the general introduction about what it does and why it's so special.	*Intermediate Builder*

17	and of course the thing might be there. I'd be showing them the thing.	*Intermediate Builder*
18	I'm thinking now about whether I should tell them about the differences between the wires.	Speculator
19	I think I would tell them the difference between the two kinds of wires to emphasize the fact that it needs—it's important to know from the beginning that it has to, like a car, it needs a source of its own power to get going just before it starts energy.	*Detail Builder*
20	So they can sort of differentiate [the types of energy] and that will help them later on in understanding several things that they need to do, about like setting up . . . how you can charge one thing while you're doing the other, and get energy for the overall machine while you're doing something else.	Advisor (2)
21	So, differentiate, describe the different types of wires and how there's electricity in it	*Intermediate Builder*
22	Going back to the—	Facilitator (1)
23	Before that, I would describe the three kinds of energy it has in each of the units to obtain the different kinds of energy—the Tablograph, the Vegetor, and the Impulse Purifier.	*Intermediate Builder*
24	OK, those are the three units . . . the three kinds of things that they would produce and the different kinds of energy—just give them an introduction to that.	Facilitator (3)
25	I'm not thinking anything now—it's sub-brain right now.	**Monitor (2)**
26	I guess I would provide them with a structure, maybe to—	*Abstract Builder*
27	. . . all this information I'm giving them, . . . I've learned it in all my classes recently.	**Memory**
28	. . . Give them a table, and have it set up for them . . . one column for each unit, what kind of energy it produces, what it needs—source of raw energy. Fill it in.	*Detail Builder*
29	Now I have to remember some of the stuff that I learned.	**Monitor (1)**
30	I would . . . well, the converters are pretty much the same.	**Memory**
31	Starting with this unit, [the] source of raw energy (pause)	*Detail Builder*
32	I'm trying to remember what these things are specifically called—the TaO.	**Architect (3)**
33	I knew I had to use them,	**Memory**
34	but maybe it might just be a source of confusion of I tried to—	Advisor (2)

35	Oh, continuing my table:	Facilitator (1)
36	sources of raw energy, how the energy is extracted for each one of the kinds . . . the needle, scanner, photoreceptor . . .	*Detail Builder*
37	I guess I'm not going to worry about these. . .	*Detail Builder*
38	Okay, that's basically their table.	Facilitator (3)
39	Then, I think this helped me when I did it:	**Memory**
40	is to give them an idea—and this is when I would demonstrate . . . one of them,	*Intermediate Builder*
41	probably the easiest one, the most complete one.	Advisor (1)
42	I guess this one skips steps.	**Memory**
43	but just first to show them the Tablograph running. Have it go . . . [and] you get a "T" in here.	*Detail Builder*
44	Then break down . . . what happened and just let them see that once.	*Intermediate Builder*
45	I know. I don't expect them to understand it	Advisor (1)
46	But I'm going to give them this flow chart I did: the unit, you get the raw energy, it goes to the convertor, it's impulse energy, and then it goes to the I-switches, it goes to the purifier—and give them this little flow chart to follow. And then how it goes from the I-switches to the O-switches and then it enters the motor, which indicates what it does . . . and say that that's an indication [that] mechanical energy's being produced.	*Detail Builder*
47	I would use a machine and show them once, and give them this more streamlined idea of what's going on. Trace as I . . . show where each [component] is on here.	*Intermediate Builder*
48	I'm contemplating now whether I should . . . , in my general intro, tell them about the parts and what each does, like what the motor indicates.	Speculator
49	I don't know if that would [make] me that much stronger from the beginning or not,	Advisor (2)
50	but so they get the idea of how one particular one flows.	Advisor (2)
51	. . . actually, at this point, I've gone through one.	Facilitator (3)
52	and then I would elaborate on each of these components . . . what the unit is and what it does—converters, . . . the I-switches . . . orient them to each particular component on the flow.	*Intermediate Builder*

53	So that's when I would do it.	*Intermediate Builder*
54	I think that it's important for them to understand how it's flowing first. . . I think they'd get more out of . . . each one . . . if they knew what it was doing and where in the circuitry it's doing it.	Advisor (1)
55	So orient them on each of those and let them . . .	*Intermediate Builder*
56	. . . I don't know whether I'd have 30 computers . . .	**Architect (3)**
57	It'd be good to give each kid a feel, to try to move the switch . . . as I'm orienting each one—to play with each one as they're going.	Advisor (1)
58	Hopefully that would be possible. I guess I'm saying what I want to say, so I'll say it's possible.	**Architect (2)**
59	and they'll get to play with them . . .	*Intermediate Builder*
60	Actually, maybe I'd tell them—	*Intermediate Builder*
61	I guess I need to think about . . . the bottom point of this. . .	**Monitor (1)**
62	if I'm trying to [get them to do] critical thinking on their own and [figure] this out and have learning be a process for them, or do I . . . just want [them] to be able to [operate] this?	**Architect (3)**
63	I have to decide what my focus is . . .	**Monitor (1)**
64	I'm thinking, I could be totally efficient [and] show them exactly how to do one of them, and then have them figure out the other ones. But if I wanted them to think—	Speculator
65	So I guess it would depend for what purposes I'm doing it.	Advisor (4)
66	I'm not sure what one I'm . . . for.	**Architect (3)**
67	But, if I had to have them well trained in half an hour because they have to run this at the diesel shop that afternoon, I'd just not worry about the learning as much.	Advisor (1)
68	. . . that would be something to think about before I did it, just why or how I want them to learn it.	**Monitor (1)**
69	Will I want them to learn from the learning or [will] I just want to . . . get them running on the thing . . . have them play with each part? . . . [is it a] how-to or an exercise in thinking? Am I doing this in class or am I doing this because I have to do it? You know, well I work at this company and I have to train . . .	**Architect (3)**
70	I guess I'd probably want them to think about it anyway. I'll assume I want them to think about it.	**Architect (2)**

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